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TORD ADOLFSSON

A spectrophotometric investigation into bright and dark regions in Taurus

Part III. The distribution of obscuring material

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A SPECTROPHOTOMETRIC INVESTIGATION INTO BRIGHT AND DARK REGIONS IN TAURUS

PART III. THE DISTRIBUTION OF OBSCURING MATERIAL

Akademisk avhandling

vilken — jämte de tidigare tryckta delarna I och II — med tillstånd av filosofiska fakulteten vid Uppsala Universitet för vinnande av filosofie doktorsgrad offentligen försvaras å universitetets lärosal 4 lördagen den 24 april 1954 kl. 10 f. m.

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TORD ADOLFSSON

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A spectrophotometric investigation into bright and dark regions in Taurus

Part III. The distribution of obscuring material

By Tord Adolfsson

With 16 figures in the text

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CHAPTER I

Introduction

In 1945, Professor K. G. MALMQUIST, the Director of the Uppsala Observatory, suggested that I might investigate the distribution of dark material in the large Taurus nebula. During the following years the necessary spectral plates were secured with our 15 cm double-astrograph. By means of these plates, magnitudes, colours, and spectral classes have been determined for 1153 stars situated in a region, limited by about $-10°$ – $-15°$ in galatic latitude and by 4^h–5^h in R.A.; the total area beeing about 100 square degrees. The exact boundaries of the region are given in Fig. 1.

For further details I shall here confine myself to references to the recent papers [1] and [3], forming Part I and II of the present investigation.

CHAPTER II

Earlier investigations

It is a well-known fact that the dark nebula in Taurus is one of the most conspicuous in the northern hemisphere. Therefore it is quite natural that it has been investigated on several occasions.

In his monograph "The distribution of the stars in space" [5], Dr. BOK has given a survey of the investigations in the Taurus nebula from the first analysis performed by DYSON and MELOTTE in 1919 up to the star counts by VON KLÜBER in 1933 and 1937. The large dispersion in the luminosity function for the stars in general, however, makes determinations based only on star counts very uncertain. Therefore, reference will be made to these early investigations only if there are details of interest in direct connection with my own discussion.

Later, MCCUSKEY in a series of papers ([14] = I, [15] = II, and [16] = III) has analysed the galatic structure in Taurus not only by means of general star counts but also using spectra, and therefore a short summary of MCCUSKEY's results will be given here.

The discussions found in the two first papers, I and II, are exclusively founded on general star counts and therefore the results obtained must be regarded as merely preliminary. It is a well-known fact that star counts in general give good information only of the total photographic absorption.

In order to obtain more reliable data, MCCUSKEY, therefore, in paper III has used spectra (the principal part being 2040 spectra in the Henry Draper Extension) as well as determinations of colour excesses for 450 early-type stars, acquired from blue-yellow colour indices. The original star counts were made over an area of not less than 600 square degrees but spectra were available only from the central part of this area. The region (centered at about $\alpha = 4^h$; $\delta = +30°$) was divided in five subregions according to the boundaries given in the following figure. The subregion numbered VI also found there is covered by spectra from the Yale Zone Catalogue. In addition, by the degree of shading the Figure 2 gives information on the surface distribution of the obscuring nebulosity in Taurus, according to the general star counts.

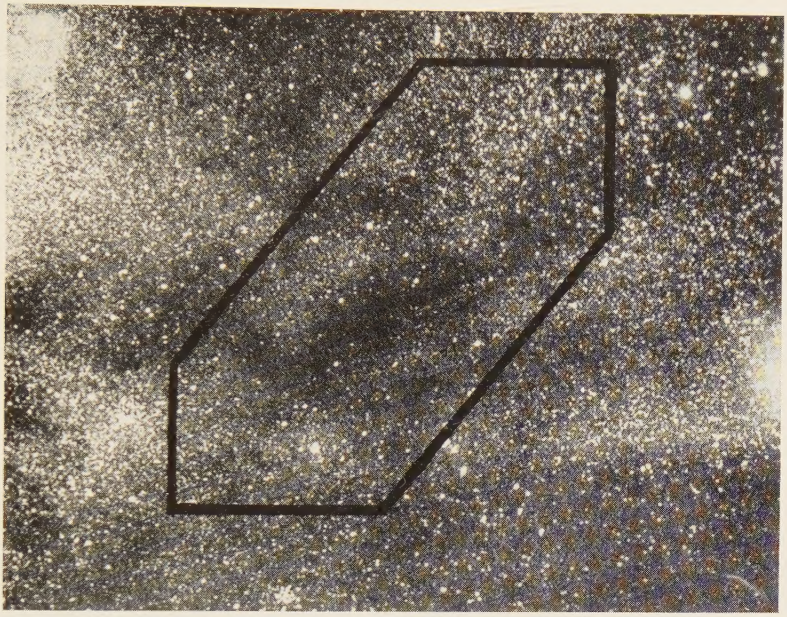

Fig. 1 a. The Taurus region investigated. A reproduction of a photograph by WOLF.

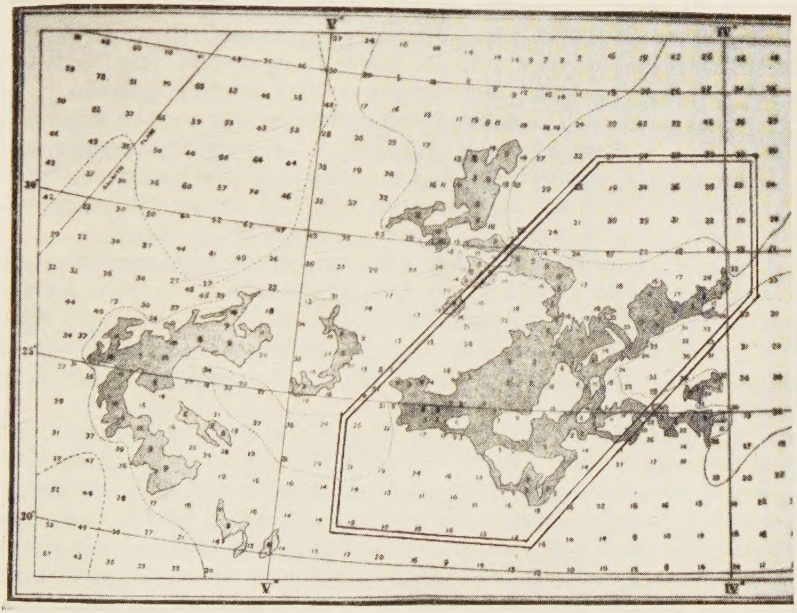

Fig. 1 b. Numbers of stars per 100 square minutes to magnitude 15.8 (photographic), according to DYSON and MELOTTE. The dark areas are shaded. Contour lines are drawn when the star density exceeds 20 and 40.

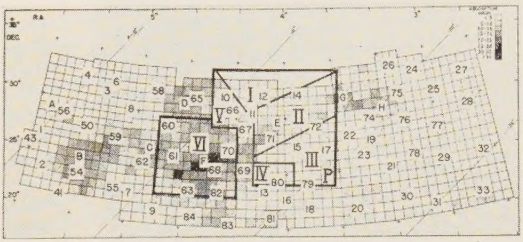

Fig. 2. The regions in Taurus investigated by McCuskey.

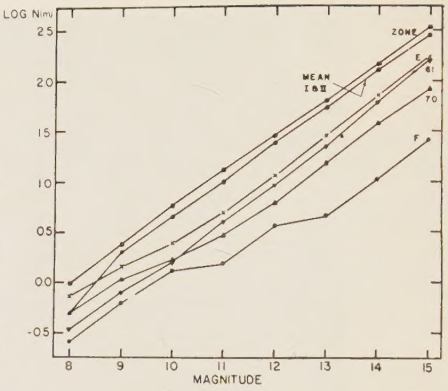

Fig. 3. Wolf diagrams for the densest nebulosities in Taurus according to McCuskey.

The distribution of the spectral types, according to magnitude for each region is found in Table 1, p. 471, in paper III. The conclusions which could be inferred from the new material at hand did not always confirm the results from papers I and II. The colour-excesses indicate an absorption of 2.0 magn. in photographic light for regions I–IV, except in region III where the absorption amounts to only 1.0 magn. Further McCuskey finds that the absorption in all cases seems to be complete up to 200 parsecs, no increase being indicated beyond. This conclusion is based on results graphically illustrated in Fig. 3 on p. 473. As seen from this figure the scattering of the points around the lines drawn is considerable, however, and because of this fact it seems to be very difficult to draw any conclusions at all from that material. In addition, however, McCuskey counted external galaxies in order to check by another method the average total absorption. Up to a limiting magnitude of approximately 18 there were 2.8, 5.5, and 2.7 nebulae per square degree, for regions I, II, and III, respectively, which in the case of a uniform nebular distribution in space would indicate an absorption of about 2 magn. in excess of that at the galactic poles.

Fig. 5 on p. 480 showing the m, log $N(m)$-curves for four small regions in the nebula, has interest with regard to my own investigation on the following pages and it has therefore been reprinted here as Fig. 3. The positions of the various small areas are found in Fig. 2. The total absorption is, according to McCuskey, found by adding 2.0 magn. to the absorption found directly from the figure with regard to the mean log $N(m)$-curve I–II.

As seen in Fig. 2, McCuskey's region VI covers a large part of the area investigated by the present author. Therefore I should like to close by citing McCuskey: "An estimate of the distance at which the dense cloud in region VI becomes effective has been obtained from m, log $N(m)$-curves similar to Fig. 5 for the separate spectral groups B8–A0, A2–A3, A5–F0, and gG5–K2. The spread in the absolute magnitude of each group is much smaller than for the stars as a whole, hence a combination of the mean M for the group with the apparent magnitude at which the m, log $N(m)$-curve for region VI definitely departs from those of regions I and II yields a resonably accurate measure of the nebula. The mean distance obtained in this way for the nebulous material in region VI is 113 ± 39 (m.e.) parsecs. We conclude

from the present study of colours combined with the star counts and spectra that the densest portions of the Taurus nebula have a very small effective thickness, probably not over 100–150 parsecs, and that the absorption on the average is about 2 magn., with certain dense spots absorbing up to 5 magn."

Chapter III

Discussion of the spectral quantities

The investigation presented here is based on magnitudes, colours, and spectral and luminosity types determined for more than 1000 stars situated within the region, whose limits have already been stated in Fig. 1. Moreover, photoelectric determinations of magnitudes and colours of about 100 stars are used. All spectrophotometric and photoelectric data are found in [3], published recently. A few words must be said about the quantities (the definitions of which are found on p. 430) found in this catalogue.

1. The magnitudes

The magnitudes are founded on grating exposures and they have been chosen so as to agree with the *scale* defined by the photoelectric equipment at this Observatory. In this connection I wish to refer to papers [2] and [3] for further details. From these papers it seems necessary to accept a grating constant somewhat greater than $G = 0.90$, which value has previously been used. The value accepted by the present author is $G = 0.96$. It may be pointed out, that a least squares solution applied to the monochromatic and photoelectric data found in Table V in [3] gives a value of $G = 0.964 \pm 0.003$ $(n \geq 2)$.

The *zero-point* is defined by means of Table II on p. 182 in [2]; this implies that the three magnitude systems found there coincide at the point where $m_{pg} = 6.00$.

If the zero-point is defined by the photographic magnitudes found in the Draft Reports, I.A.U., Rome Meeting, 1952, -0.09 magn. must be added to the original catalogue values.

If the monochromatic magnitudes are compared with ordinary integral magnitudes the systematic differences tabulated in Table XI must be added. These corrections are the mean differences between $m_{pg}-m_{sp}$ not only of photoelectric but also of ordinary photographic magnitudes, most of which are found in [11] and [23]. The total number of common stars used is about 1000.

No systematic differences in the monochromatic magnitudes have been found till now.

2. The colours

The colours seem to be comparatively accurate. Only in the case of very faint stars there are obvious systematic errors. Above a certain magnitude limit the colours came out too small. Colours, for which the quantity $m_{sp} + C_{sp} \geq 11$–11.5 in the bright or comparatively bright regions and ≥ 11.5–12 in the dark regions must therefore not be used directly.

The cause for this systematic difference has been investigated. It principally depends on the extrapolated part of the density curve of plates 7–10 (comp. Table I on p. 427 in [3]) which in most cases has been drawn too steep. Thus the mean

errors found in Table X on p. 448 in [3] are too small in the case of very faint stars; determinations of these errors from a density curve correctly drawn give about 0.10–0.15 as a result. Therefore I have preferred not to give any systematic corrections at all to be added to such colours.

The application of the well-known secans-formula for eliminating the differential atmospheric extinction includes an uncertainty which, of course, may produce systematic errors, depending on the declination of the stars. I have, therefore, completed Table V on p. 438 in [3] with a few more photoelectric determinations of colours (see p. 505) in order to investigate if such an effect could be traced with certainty. However, I could not find any such effect.

3. The remaining quantities which have been measured

The quantities g, c, 4400, and 4227 seem to be of approximately the same accuracy over the whole magnitude range.

The values of $H\gamma$, $H\delta$, and K are somewhat uncertain when $m + H\gamma$, $m + H\delta$, and $m + C + K$ exceed those limits which were given above in the case of the colours. It must be pointed out, however, that in the actual cases a systematic error is by no means as obvious as in the case of the colours.

For the stars in the catalogue marked with an asterisk there are spectrophotometric data available only from a comparatively faint spectral image on one of the spectral plates 1–5 (Table 1 on p. 427 in [3]). The spectral quantities of such stars must therefore not be given the normal weight.

4. The spectral and luminosity classes

The spectral and luminosity classes given in the catalogue are approximately the same as those introduced by LINDBLAD about 30 years ago. These classes have, with small modifications, been used thereafter in all spectrophotometric works performed at Uppsala or in Stockholm.

Later the classification has been based on registrograms of the spectra. Thus we have, in addition, got monochromatic magnitudes and colours as "by-products", which justifies a method much more laborious, of course, than the original direct visual classifying on the spectral plates. In this connection it may be pointed out that very recently WESTERLUND has shown that in spite of the small dispersion used here a still more detailed luminosity classification can be performed when tracings obtained with our self-recording microphotometer are utilized [28, 29].

Unfortunately it is not possible to make a direct comparison between the original Uppsala classification and the system used by the present author, as the material at hand does not contain a single star classified at Uppsala or in Stockholm previously. However, indirect comparisons (compare VANÄS [26] p. 34) indicate that no marked difference exists between the system of the present catalogue and earlier determinations. Moreover, the comparisons with SCHALÉN's classification of stars in Auriga (pp. 519–524) show that the Auriga and the Taurus stars are classified in a practically identical way.

As shown in the catalogue p. 442–443, it seems to be possible further to classify the giant M-stars with the aid of the calcium line at 4227, and therefore those stars have been devided into Mo, M3, and M5 stars.

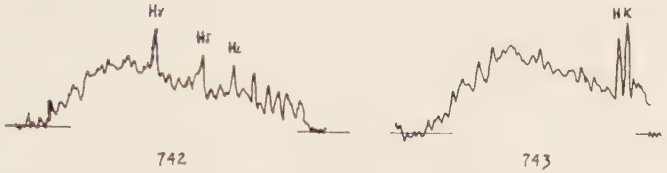

Fig. 4. Two stars with bright H- and K-emission lines.

5. Peculiar stars

Within the region investigated, there are stars with H- and K-emission lines. These stars have been marked in col. "K" in the catalogue with "E". Originally I intended to reach such stars of, at least, magn. 13.5 using prism II. Several unforeseen difficulties forced me, however, to postpone that work.

Nevertheless it may be of interest to show a couple of registrograms for such stars obtained with the aid of prism I. It is seen from these registrograms that the quality of the spectral images is still very good in spite of the faintness of the stars.

In 1949 Joy published in the Astrophysical Journal [9] a catalogue containing a great number of stars with emission H- and K-lines, and very recently this number was considerably increased by a Tonanzintla paper [8]. In spite of these papers, however, a thorough investigation of stars of this type might be of great interest, since there are no well-determined magnitudes available yet.

Finally, one drawback should be pointed out, which influences spectrophotometric works when using rather small instruments. In certain cases it may be difficult to decide whether the spectral images are partly overlapping or not. A star's spectrum, indicating pecularities, is in the catalogue marked by "p", but this "p" does not necessarily mean that the star is really peculiar. Most certainly, however, almost all dubious cases have been discovered. Furthermore the use of the Tonanzintla plates and the plates obtained by the prism II have facilitated the elimination of coincidences.

Chapter IV

A preliminary analysis

As already mentioned, the following discussion is based on magnitudes, colours, and spectral and luminosity types for more than 1000 stars in the region on Fig. 1. This region was divided into areas of 4 5 square degrees, the Wolf diagrams of different spectral types were constructed in the usual manner, and from these curves and the apparent distribution of dark and bright matter I tried to join the small areas to form larger ones. In addition the distribution of colour-excesses was used (the colour-excesses used were only preliminary): I thus assumed that the total photographic absorption and the colour-excess was intimately correlated. In this way five different areas arose, and I hoped these would be rather homogeneous. In diagrams the frequency curves of the relative colour excesses were constructed in the case of early type stars. These diagrams seemed to indicate the existence of a single dark nebula as an approximately normal distribution around an excess value of 0.10 magn. was found. The frequency distribution according to magnitude for

each region and for different spectral types were tabulated and then the statistical methods published by MALMQUIST [12, 13] and LYTTKENS [10] were applied.

Different spectral classes gave, however, very different values of the distance of the nebula, and, moreover, the σ-values found deviated considerably from the values usually accepted. Such puzzling results can be created by many factors, *e.g.* the 5 different areas were not homogeneous enough with regard to the absorption; there were several dark clouds; small number of stars, etc.

The possibility of an extraordinary distribution of stars in space in this particular region could not be considered out of the question either, but by using a method, best described as "trial and error", the peculiarities were entirely eliminated. The results of the investigation and the final method used being accounted for later, I shall here confine myself merely to summarizing the preliminary results in the following paragraphs.

1. One single absorbing screen cannot possibly account for the observed apparent distribution of the stars.

2. The distribution of the dwarf stars indicates the existence of near-by dark nebulosities at a distance of 30–40 parsecs or less than that.

3. There are dark veils also within the regions which I originally considered free from absorption (the 29–33°- and 21–23°-zones).

4. I did not originally expect to find any conspicuous homogeneity of the distribution of stars in Taurus, but limiting the investigation to more homogeneous space elements I found SEELIGER's law valid for the whole region of the present investigation, at least within comparably short distances. That means that the distribution function of m is

$$N(m) = C \cdot 10^{\beta m},$$

where β can be determined from the straight line parts of the $\log N(m)$-curves, as

$$\beta = \frac{\log N(m_2) - \log N(m_1)}{m_2 - m_1}.$$

The following table contains the results. The mean errors are 0.03–0.04 except in the case of classes A0σ -, σ, and dG5. In the latter instances the values were considerably scattered.

5. Preliminary determinations of the factor k in $A = k \cdot E$ (in this case $\Delta A = k \cdot \Delta E$ was used) where A = the total photographie absorption and E = the colour excess gave k-values varying between 8.5–11. (The colour is $C_{sp} = m_{3910} - m_{4400}$.)

Table I

Sp.U.	β
A0σ +, σ	0.44:
A0μ	0.48
A2, 3	0.44
A5F0	0.40
F2F5	0.54
F8G0	0.56
dG5	0.68:
g-stars	0.47

CHAPTER V

Determination of normal colours

1. Determination of normal colours at the galactic pole

In 1936 MALMQUIST published an extensive photometrical investigation in a region at the northern galactic pole [11]. In this region colours and magnitudes were given down to magnitude 13.5. This material was later on extended by spectral types secured with the Stockholm astrograph. In order to calibrate the Stockholm determinations in Uppsala values the present author, inspired by professor MALMQUIST, has determined spectrophotometric data of common stars, previously determined by MALMQUIST. This material has not yet been completely worked through, but the data already obtained are sufficient to admit determinations of mean colours within each spectral class (of the Uppsala system) at the galactic pole with high precision.

The quantities found in Table II are obtained from the following material.

1. The present author has determined, at the galactic pole, spectral classes of about 150 bright stars in the same way as described on p. 440 in [3]. The density curves used are, however, founded on the magnitudes from MALMQUIST's catalogue. The scale thus obtained must, provided MALMQUIST's magnitudes are on a correct scale, differ from that founded on the grating of the Uppsala astrograph (I originally used the grating value $G = 0.90$ instead of the value G = 0.96, which was later accepted). Once more I wish to point out here that all spectral quantities found in my catalogue are given in the original system (founded on $G = 0.90$) *except* the magnitudes, which are on a correct scale ($G = 0.96$).

All spectral colours at the galactic pole were reduced in the same way as before in Taurus, but in addition they must be reduced by 7 percents if they are to be compared with the colours in my catalogue. The values in Table 6 in [3], containing the scheme of classification must, of course, be reduced accordingly. This procedure was justified in that a comparison between photoelectric magnitudes (see 2, below) and MALMQUIST's magnitudes of common stars indicated that a scale deviation of more than about 1 per cent was not to be suspected. Furthermore, the correctness of this procedure was verified once more, when the spectral classes determined by the present author were, in a diagram, compared with Harvard spectral classes of common stars. All the A–K-stars were scattered only to a small extent around the 45-degree line.

2. Thanks to Messrs. PETERSON and LJUNGGREN, several photoelectric determinations of colours (hence also blue magnitudes) of common stars were available. These determinations have been performed as before with the Uppsala refractor equipped with a photoelectric photometer, a description of which is found in WALLENQUIST's paper "Photoelectric photometry at the Uppsala Observatory" [24]; the single difference in method now being the application of extinction corrections, which was in this case determined by the aid of extinction stars. Thus, the colours were reduced to "no atmosphere". It should be emphasized here that the spectral colours in Taurus as well as at the galactic pole were reduced to a zenith distance of 30 degrees; the photoelectric colours in Taurus were reduced to zenith, and the photoelectric colours at the galactic pole to "no atmosphere". The differences of the reduction methods give rise to small systematic differences in colour of different spectral types

(see EGGEN [6]). In the case of the colours given below, the colour-interval and consequently the systematic differences mentioned above are found to be negligible, in a preliminary discussion at least.

To obtain the same zero-point at the galactic pole and in Taurus the photoelectric colours were reduced to the mean colour system, defined by the measurements performed on March, 18, 19, and January 21.

3. In a few cases I had the opportunity to borrow from MALMQUIST the determinations of $H\gamma$ and $H\delta$ of early type stars, for which photoelectric colours were determined but for which I myself have not yet secured any data. Thus these stars too could be classified in the same luminosity system as the rest.

The following table contains the results, the columns being, respectively, spectral class, the mean photoelectric colour and mean error, the dispersion within the spectral class, the number of stars used; spectral colour and mean error, the dispersion within the spectral class (only approximate) and the number of stars used.

Thus s_1' denotes the dispersion around the mean value caused by 1) the dispersion s_1 within a given spectral class even if the observed value is exact, and 2) the dispersion caused by errors in the observed value. In case of photoelectric observations 2) may be neglected and we get s_1 directly.

The mean errors have been computed by means of the well-known formula

$$\varepsilon = \sqrt{\frac{\Sigma \Delta^2}{n(n-1)}}.$$

It may be mentioned that only one B$\tau-$ and one A0$\sigma+$ star were available. In both cases a value of $C_{sp} = 0.10$ was obtained.

Table II

Sp.U.	C_{Pe}	s_1	n	C_{sp}	s_1'	n
A0μ	-65 ± 5.5	12	5			
A2, 3	-44 4.7	9	4	38.0 ± 2.5	5.0	4
F0, 2	-39 2.2	5	5	46.2 2.5	5.0	4
F5	-32 1.6	5	11	53.0 1.3	4.9	15
F8	-29 1.9	5	8	58.2 2.0	7.3	14
G0	-23 1.1	5	17	64.6 1.2	5.5	21
dG5	-19 2.7	8	8	73.5 1.7	7.8	21
dG8	+04 6	12	4	90.0 3.2	12	14
dK0	+09		1	107		1
dK2	+07		1	109		1
gG5	+03		2	80		2
gG8	+21 2.3	8	10	104 3.2	8	6
gK0	+31 2.5	9	12	120 4.3	8	11
gK2	+46 4.6	11	6	145 3.2	9	8
gK5	+73		3	169 13	22	3
gM0				215 18	26	2
gM3	+78		1	207		1

2. The relation between the photoelectric colours and the spectral colours

In part II of this investigation I postponed a discussion of the spectral colour equivalent $C_{sp} = m_{3910} - m_{1400\,(4360)}$, but because a thorough discussion of this equiv-

alent already has been made by WESTERLUND [28], it does not seem necessary to give more than some additional properties concerning this equivalent with special regard to the photoelectric colour equivalent ($C_{pe} = \bar{m}_{4200} - \bar{m}_{5200}$). In this connection I also want to refer to the very recent papers by MORGAN, HARRIS, and JOHNSON ("Some characteristics of color systems" [17]) and SCHALÉN ("Spectrophotometry with a Schmidt telescope: A study of different colour-equivalents and the law of space-reddening" [22]).

Before proceeding a few words about some recent photoelectric determinations may be said.

As already mentioned it was found necessary to test the applied extinction correction as thoroughly as possible. Therefore the original photoelectric determinations collected in Table V in the catalogue were completed with colour determinations of stars situated within the 21 23 -zones. These determinations were performed on the following nights: 10/11, 12/11, 13/11, and 15/11 1953. The weather conditions were not perfect except during the night 13–14/11. The determinations on that night were therefore given the same weight as all determinations made on the other nights together.

In this connection I wish here to express my thanks to Mr. PETERSON for his valuable assistance when the determinations were made.

The following table contains the result.

Table III

Star No.	C_{Pe}	Star No.	C_{Pe}
812	−08	1035	−37
869	−15	1036	−39
891	−24	1040	−45
965	−46:	1044	−39:
966	−51	1124	−46
977	−61	1133	−17
990	−62	1140	−36
993	−37	1144	+04

(: only one determination)

Assuming the intrinsic colours of a given star to be $C_{pe} = C^N_{pe}$ and $C_{sp} = C^N_{sp}$, respectively, a selective absorption must, of course, affect these two original values in different ways; let us suppose that these differences are $\Delta C'^N_{pe}$ and $\Delta C'^N_{sp}$, respectively. Is it possible then, that the quotient between $\Delta C^N_{pe} : \Delta C'^N_{sp}$ can be determined in some way from the present material?

It is immediately evident that if we use only stars of a special spectral type, A0μ-stars, for instance, from a region showing very irregular obscuration, the points in a diagram with the coordinates $(C^N_{pe} + \Delta C^N_{pe};\ C^N_{sp} + \Delta C^N_{sp})$ must be scattered around a certain line, where the inclination would be $\Delta C'^N_{pe} : \Delta C'^N_{sp}$, at least approximately. If thus the stars radiate as black bodies, if the Planck formula is substituted for that of Wien, and if the λ^{-1}-law is valid, we easily get the equation of the straight line along which the reddened stars will be displaced (see *e.g.* eq. (5) and (10), pp. 30–31 in [22]). In the actual case one of the points, that at λ 5200 in the case of the photoelectric colour, is situated on the opposite side of λ 4800 than the other,

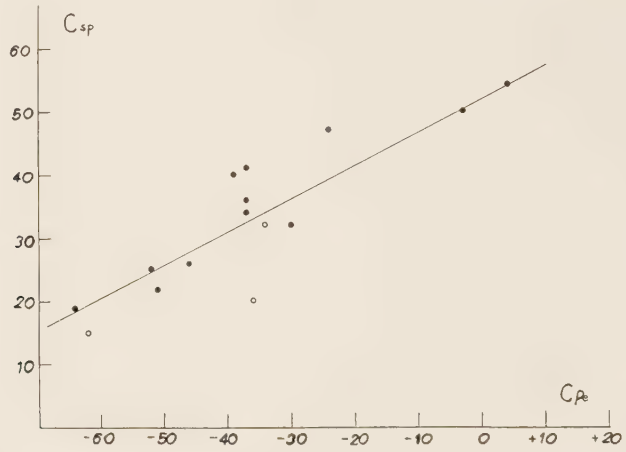

Fig. 5. The relation between photoelectric and spectral colours in the case of reddened A0μ-stars. Unit: 0.01 magn.

which fact may cause difficulties in the case of late type stars; when two gradients are used to represent the continuous radiation of stars, the wave-length interval must be divided in two parts by means of the point at λ 4800 [4].

The following figure shows all A0μ-stars of which both photoelectric and spectral colours are available. As is seen from this figure a value of approx. 1:2 is easily obtained. If A0σ+, σ-stars are used instead, we get the same result.

This value can also be arrived at in another way. In 1948 [30] WHITFORD published a curve giving the selective absorption as a function of λ (or of $1/\lambda$). If we use this curve and determine the quotient searched for above, we again obtain a value very near to 0.50. It must, however, be pointed out that the latter method is not free from critisism, since the values defining that curve seem to be uncertain because of errors in the adopted effective wave-lengths of STEBBINS' filter. SCHALÉN [22] and VAN RHIJN [25] have found the same deviations from STEBBINS' and WHITFORD's values when measurements of common stars are compared. It is, however, not necessary to search for a value which is better than that one already derived. The value 0.5 will therefore be used in the following discussion.

3. "Normal colours" in Taurus

When mean colours of all spectral types at the galactic pole are determined the question spontaneously arises whether the same mean colours would really be obtained also in other unobscured regions of the sky, *e.g.* in Taurus. In other words, one may ask if it is possible to assume the existence of "normal colours".

To obtain an answer to that question we may now use the present material to analyse the colours in Taurus, given in Table V in [3] and in Table III in the present paper. In the following Table IV all available data are summarized in the case of A0μ–dG8 stars. The photoelectric colour excesses in Taurus are first calculated, using the mean photoelectric colour values at the galactic pole. The excesses are then multiplied by the factor 0.5 and are thus reduced to the scale of the spectral colours. Hence, the excess values of the spectral colours could be obtained by

Table IV

No.	Sp.U.	C_{Pe}	C^N_{Pe}	Δ	$\frac{1}{2}\Delta$	C_{sp}	n	C'_{sp}
4	G0	−09	−23	14	7	74	1	67
37	A2	−48	−44	−4	−2	32	3	34
53	A0μ	−51	−65	14	7	22	3	15
104	dG5	−11	−19	8	4	79	4	75
112	A2	−40	−44	4	2	30	3	28
132	A0μ	−34	−65	31	16.	32	2	16
135	G0	−15	−23	8	4	64	2	60
152	A0μ	−46	−65	19	9′	26	3	17
244	dG8	+09	+04	5	3.	107	2	104
257	A0μ	−52	−65	13	6′	25	5	19
300	dG5	−09	−19	10	5	75	2	70
307	A0μ	−37	−65	28	14	36	5	22
320	F8p	−15	−29	14	7	72	4	65
367	G0	−15	−23	8	4	65	5	61
441	A0μ	−03	−65	62	31	50	3	19
455	F0	−26	−39	13	7.	53	1	46
458	G0	−19	−23	4	2	62	2	60
483	A2v	−21	−44	23	11′	56	8	45
489	dG5	−06	−19	13	7.	72	8	65
511	dG5	−03	−19	16	8	77	6	69
533	A2	−27	−44	17	8′	47	4	39
543	F8	−26	−29	3	2.	61	6	59
550	A2	−33	−44	11	5′	52	7	47
558	A0μ	−64	−65	1	1.	19	4	18
577	F2	−36	−39	3	1′	54	4	53
597	A2	−22	−44	22	11	44	5	33
611	F8	−16	−29	13	7.	66	4	59
612	A2	+08	−44	52	26	54	5	28
613	F5	−27	−32	5	2′	58	4	56
632	A0μ	−30	−65	35	18.	32	4	14
692	dG5	−10	−19	9	4′	81	4	77
693	dG8	+06	+04	2	1	85	4	84
763	A3p	−52	−44	−8	−4	13:	3	17:
770	A0μ	+04	−65	69	35.	54	6	19
801	dG8	+10	+04	6	3	106	4	103
802	F0	−38	−39	1	0′	52	2	52
804	G0	−15	−23	8	4	65	5	61
807	A2	−07	−44	37	19.	59	3	40
812	A3	−08	−44	36	18	53	6	35
820	A2	+06	−44	50	15	56	6	31
821	G0	−20	−23	3	1′	77	2	76
869	A2	−15	−44	29	15.	52	4	37
878	F8p	−27	−29	2	1	67	2	66
891	A0μ	−24	−65	41	20′	47	3	27
990	A0μ	−62	−65	3	2.	15	2	13
993	A0μ	−37	−65	28	14	41	3	27
1035	A0μ	−37	−65	28	14	34	3	20
1036	A0μ	−39	−65	26	13	40	3	27
1040	A2	−45	−44	−1	0′	33	1	33
1133	F8	−17	−29	12	6	63	2	57
1140	A0μ	−36	−65	29	15.	20	2	5
1144	A2	+04	−44	48	24	59	1	35

calculations. If the original spectral colours in Taurus are reduced by the excess values found in this manner, we should expect to obtain the "normal values", i.e. the spectral colours are thus freed from selective absorption. Forming the mean values of each spectral class we immediately have the possibility of testing the surmise that normal colours exist. Should these values prove to be close to the ones obtained at the galactic pole, we should, moreover, be justified in improving the values previously obtained.

The individual values within each spectral class are:

A0μ: 15, 16, 17, 19, 22, 19, 18, 14, 19, 27, 13, 27, 20, 27, 5
A2, 3: 34, 28, 45:, 39, 47, 33, 28, 17:, 40, 35, 31, 37, 33, 35
F0: 46, 52
F2: 53
F5: 56
F8: 65:, 59, 59, 66:, 57
G0: 67, 60, 61, 60, 61, 76
dG5: 75, 70, 65, 69, 77
dG8: 104, 84, 103.

The values are arranged according to the catalogue number of the stars; that means that a possible run in the values with decreasing declination might be traced from the sequences. As seen from the table the values are relatively constant. Therefore it does not seem to be improbable that the colour system is free from systematic errors, except that already mentioned on p. 499.

The giant stars gG5–gM are then treated in the same way. Neither can any appreciable differences between the mean colours of the giant stars at the galactic pole and in Taurus be traced.

From the preceding discussion we find that nothing contradicts the supposition of the existence of normal colours.

Table V

Sp.U.	C^N_{sp}	s'_1	n	C'_{sp}	s'_1	n
A0μ				18.5±1.3	5.0	15
A2, 3	38.0±2.5	5.0	4	34.7 1.6	5.6	13
F0, 2	46.2 2.5	5.0	4	50		3
F5	53.0 1.3	4.9	15	56		1
F8	58.2 2.0	7.3	14	60.3 2.0	4.0	4
G0	64.6 1.2	5.5	21	64 2 2.9	7.0	6
dG5	73.5 1.7	7.8	21	71.2 2.2	4.8	5
dG8	90.0 3.2	12	14	97.0 6.5	11	3
gG5	80		2	91		1
gG8	104 3.2	8	6	100		2
gK0	120 4.3	8	11	130 3.3	8.1	6
gK2	145 3.2	9	8	151		2
gK5	169 13	22	3	194 8.8	15	3
gM0	215		2	192		2
gM3	207		1	220		2

$(n = p)$

4. The normal colours of A0σ+, σ stars

As already mentioned, the present material at the galactic pole contained only two stars of Bτ- and A0σ · types, the spectral colour being 0.10 for both. The material

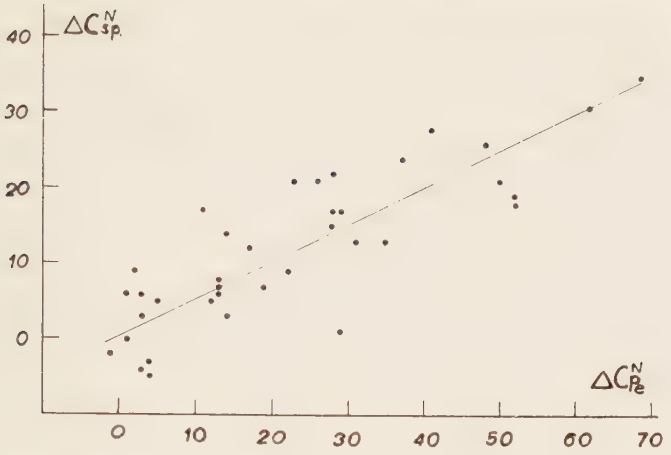

Fig. 6 a. The relation between ΔC^N_{sp} and ΔC^N_{pe} in the case of early type stars and dwarf stars.

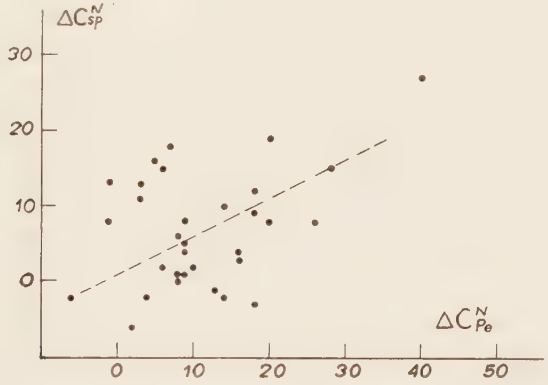

Fig. 6 b. The relation between ΔC^N_{sp} and ΔC^N_{pe} in the case of late type stars.

in Taurus contains on the other hand a great many A0σ + and A0σ stars, (but only very few B-stars!) and it would be unfortunate if these very luminous stars could not be used for the determination of the colour excesses. Therefore I have used earlier determinations of normal colours. Only the difference in the spectral colour between the class A0μ and the combined class A0σ +, σ is required. (It is a well-known fact that the difference in colour between A0σ + and A0σ stars is very small.) Fortunately an extensive material exists: (compare [27] p. 83) SCHALÉN, ÖHMAN, WERNBERG, and WESTERLUND have given "normal colours" of the stars, which are of interest here. In most cases these authors used exactly the same classes as have been used by the present author, and in these instances, therefore, I obtained the values directly. Also in the remaining cases a system directly comparable with the present one was easily obtained. In the case of WESTERLUND's Table 12 in [28] I wish to point out that the colour equivalent C'_2 used there is approximately the same as C'_{sp} used by me, but reduced for the influence of hydrogen absorption. It is easy to get values comparable with C'_{sp} by means of eq. (9) and

values of D' determined either from Fig. 16 or Fig. 18, or the catalogue values of $C_2 = C_{sp}$ may be used direct.

The mean difference between $\bar{C}_{sp,\,A0\sigma+,\,\sigma}$ and $\bar{C}_{sp,\,A0\mu}$ was in all cases found to be 0.05 magn.

5. A discussion of the zero-point differences in the colour systems

There is another possibility of testing the correctness of the normal colours, and at the same time of getting some information about the zero-point differences in the photoelectric and spectral colour systems in Taurus and at the galactic pole.

Let us suppose, that the quotient mentioned on p. 505 is k_1 in the case of early type stars and k_2 in the case of late type stars, the difference being caused by a slight difference in the wave-length interval used. If there are zero-point differences Δ_1 and Δ_2 between the photoelectric and the spectral colour systems in Taurus and at the galactic pole, respectively, we arrive at

$$\frac{\Delta C^N_{sp} + \Delta_2}{\Delta C^N_{pe} + \Delta_1} = k_1 \quad \text{and} \quad \frac{\Delta C^N_{sp} + \Delta_2}{\Delta C^N_{pe} + \Delta_2} = k_2,$$

if the same notations as before are used. We get

$$\begin{cases} \Delta C^N_{sp} = k_1 \cdot \Delta C^N_{pe} + (k_1 \Delta_1 - \Delta_2) & \text{and} \\ \Delta C^N_{sp} = k_2 \cdot \Delta C^N_{pe} + (k_2 \Delta_1 - \Delta_2). \end{cases}$$

If k_1 and k_2 differed considerably from each other it should be possible to determine Δ_1 and Δ_2 separately; in the actual case we get only $k \sim k_1 \sim k_2$! $k \cdot \Delta_1 - \Delta_2$ is graphically illustrated in a diagram as the ordinate at the origin of a straight line with ΔC^N_{pe} and ΔC^N_{sp} as variables (see Fig. 6). As seen from this figure we get from early type stars: $^1/_2 \cdot \Delta_1 - \Delta_2 = 0$. It is, of course, not possible to *prove* that the differences Δ_1 and Δ_2 are equal to zero; but it seems *probable* that they are. (If one of them is zero, the other must be so too!)

Fig. 6 b shows the great dispersion in the case of late type stars.

6. Comparison with mean colour values determined by Schalén

The preceding discussion justifies the combining of the material in Taurus and at the galactic pole when the final normal colours are determined. We obtain the following mean values which have been adopted as normal colours:

Table VI

Sp.U.	C^N_{sp}	C^N_{pe}	Sp.U.	C^N_{sp}	C^N_{pe}
A0σ, σ+	14	−77	dG8	91	+04
A0μ	19	−65	dK0	100	+10
A2, 3	35	−44	dK2	110	
A5	40		gG5	83	+03
F0	45	−39	gG8	103	+21
F2	48	−39	gK0	123	+31
F5	53	−32	gK2	146	+46
F8	58	−29	gK5	182	+70
G0	64	−23	gM0	204	+75
dG5	72	−16	gM3	214	+80

It is very interesting to compare these values with the mean colour values found in SCHALÉN's papers [20] and [21]; we may expect that the regions investigated by SCHALÉN are relatively free from obscuring material. If we use Table 9 on p. 19 in [20] and Table 6 on p. 11 in [21] and if we, moreover, divide the A0-stars into luminosity classes according to the catalogues, we obtain the following values which are to be compared with the corresponding values given by the present author:

Table VII

Sp.U.	$C_{sp,\ T-s}$	$C_{sp,\ +20°}$	Δ_1	$C_{sp,\ +40°}$	Δ_2
A0σ+, σ	14	1	13	−2	16
A0μ	19	8	11	+1	18
A2, 3	35	16	19	14	21
A5	40	22	18	23	17
F0	45	25	20	26	19
F2	48	30	18	32	16
F5	53	34	19	33	20
F8	58	38	20	40	18
G0	64	44	20	46	18
dG5	72	53	19	53	19
dG8	91	83	8	79	12
gG5	83	67	16	65	18
gG8	103	90	13	85	18
gK0	123	115	8	108	15
gK2	146	156	−10	135	11
gK5	182	181	1	174	8
gM0	204	184	~20	186	~20
gM3	214				

As is immediately seen from this table the differences are remarkably constant, especially the comparison with the 40°-zone gives almost identical values. This is perhaps what should be expected as this region is undoubtedly more free from obscuring matter than the 20°-zone.

Even if most of the values given in Table VI thus are certain, there are nevertheless normal colours which have not until now been determined with sufficient precision; the differences indicate, that when the colour excesses are later formed, spectral classes later than G8 must not be used. In the case of those late type stars, the dispersion within the spectral class is too great, as can also be seen from Table V or Fig. 6 b.

7. The relation between photoelectric and spectral normal colours

Fig. 7 shows the relation between photoelectric and spectral normal colours. If this relation is constructed in Fig. 9 in [3] we find that only a few stars are situated on the lines. Most of them fall besides the normal relation towards the right; that indicates that all stars in Taurus with a few exceptions are reddened. This figure immediately provides some information concerning the advantage of combining

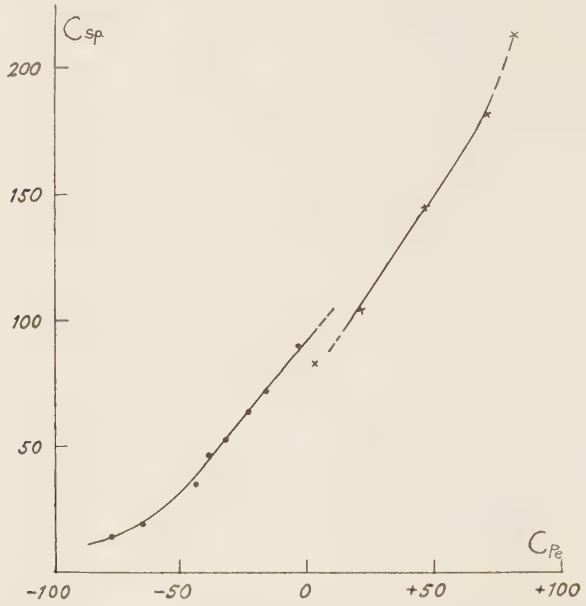

Fig. 7. The relation between spectral and photoelectric normal colours. The g-stars are denoted by crosses. Unit: 0.01 magn.

photoelectric and spectral determinations of colours. Some interesting conclusions may further be drawn from the normal relation.

1. In the case of very early type stars the spectral colours are very suitably used when colour excesses are to be determined, as there is only a slight increase in colour from class to class; that means that the dispersion s_1 is small. (In this connection I also want to refer to EKLÖF's paper [7] Fig. 81).

2. In the case of very early type stars the photoelectric colours are not specially suitable for determinations of colour excesses *if* a division only using the classes Bτ, $\tau-$, and so on can be used. In the remaining classes, from A2, 3 and so on the photoelectric colours are superior to the spectral ones.

3. It seems to be possible to get a homogeneous spectral colour system over areas widely separated by using additional photoelectric determinations even if the different areas are obscured in a very different way. If the light from a star is not affected by any selective obscuration we get a point on or near the lines found there. A selective absorption moves the point along a line with the inclination $\sim 1:2$ for early type stars in our case. If we thus select stars giving points on the diagram where the inclination is from the beginning 1:2, this very line is only extended to the right. Independently of the different obscuration this line can always be fixed in a correct manner, and, moreover, the assumption that $k-\frac{1}{2}$ may be tested every time.

Chapter VI

The distribution of dark material in Taurus as found from the colour excesses

1. Distance moduli and colour excesses

In the following Table VIII, the colour excesses and distance moduli $m - M_0$ are collected for stars with well-determined colours ($m + C \leq 11.1$–11.2 in all zones except 24°–28° where $m + C \leq 11.5$–11.6).

The same mean absolute magnitudes $\bar{M}_{pg}$ and dispersions σ which have been used here many times before have been utilized; that is the following values have been adopted:

Table VIII a

Sp.U.	$\bar{M}_{pg}$	σ
A0 σ+	−0.4	0.5
A0 σ	+0.3	0.5
A0 μ	+1.0	0.5
A2, 3	+1.9	0.5
A5, F0	+2.5	0.8
F2, F5	+3.5	0.8
F8, G0	+4.5	0.8
gG5 − M	+2.1	1.0

In the case of dG5 and dG8 stars, which also have been used, the mean absolute magnitudes 6.1 and 6.6 have been adopted.

2. The distribution of the colour excesses with regard to $m - M_0$ (uncorr.)

In the following figures, maps are given which show the distribution of obscuring material. The mean excess values found to the right of and beneath the maps are calculated in areas, the widths of which are two degrees, as is indicated in the figures. The framed values are the mean value of all excesses given on this map. Summarizing the values found in that way we obtain when all available spectral classes are used:

$m - M_0$	$\bar{E}$	
≤ 5	6.4	
5– 7	6.3	
7– 8	12.7	Unit: 0.01 magn.
8– 9	11.6	
9–10	12.4	

The colour excesses clearly confirm the preliminary results found by means of the Wolf diagrams. With the exceptions mentioned below, we thus have:

A glance at the first map will show, that practically all stars are coloured. This means that a selective absorption is fully developed already at a distance less than

Table VIII

No.	$m-M_0$	E	No.	$m-M_0$	E	No.	$m-M_0$	E	No.	$m-M_0$	E
2	8.6	+06	154	4.4	00	329	8.7	+20	521	3.9	+03
3	8.6	+04	157	8.7	+11	332	6.7	+06	522	6.1	+03
4	5.1	+10	158	3.4	+09	334	10.1	+15	523	9.3	+11
12	9.2	+09	159	4.5	+04	340	8.4	00	527	6.1	+06
14	7.9	+08	160	9.6	+11	348	7.2	00	530	7.1	+13
18	9.6	+08	161	7.5	+04	350	6.4	+03	533	7.6	+12
19	7.2	00	162	9.9	−01	353	3.6	+03	534	6.4	+04
23	8.5	+08	163	9.3	+10	354	8.3	+10	539	4.5	+02
24	8.4	−13	165	9.6	+10	355	5.3	−21	540	8.8	+10
27	9.6	+14	166	5.8	−02	360	8.5	+12	543	4.3	+03
29	10.6	+12	161	7.0	+04	361	8.5	+06	549	4.7	+03
30	9.4	00	169	8.1	+09	365	8.7	+03	550	7.0	+17
32	9.0	+12	173	7.8	−04	367	3.6	+01	558	4.7	00
33	8.2	+05	177	5.7	+09	368	8.1	+25	559	4.8	+05
37	5.7	−03	179	7.5	+08	369	5.4	−02	560	5.5	+06
39	4.3	−02	182	6.0	+13	372	10.1	+13	566	5.8	+09
41	9.3	+15	187	8.3	+10	378	9.6	+07	567	3.3	+03
42	8.8	−02	188	9.6	+08	379	6.9	+06	570	10.1	+36
44	8.9	+04	190	10.6	+12	382	6.9	+13	573	8.1	+03
45	8.4	−10	191	4.0	+04	395	6.4	+12	577	5.2	+06
47	9.7	+11	194	8.3	+19	397	7.8	+16	578	8.7	+06
51	7.0	+08	196	8.4	+18	403	6.0	−03	580	5.9	+10
53	8.2	+03	204	8.8	+26	406	7.9	+12	581	5.7	+08
64	7.1	+12	207	5.5	−03	407	8.6	−13	597	6.3	+09
66	8.9	+01	220	7.6	+25	409	7.8	+05	599	6.1	+06
69	9.9	+11	223	3.1	+07	410	7.2	+08	601	4.7	+09
73	5.5	−02	229	8.7	+23	413	5.7	+03	603	6.5	−06
76	9.7	+13	230	8.2	+17	422	6.1	+15	607	4.7	+04
77	5.4	+02	233	8.8	+05	425	6.2	+10	611	5.2	+08
78	8.7	+06	234	7.4	+08	434	5.6	+07	612	8.4	+19
80	7.3	+08	238	8.2	+15	441	8.3	+31	613	6.0	+05
93	5.1	−04	240	8.6	+16	452	9.7	+21	619	5.4	+07
104	3.1	+07	241	3.4	−11	453	7.9	+26	620	9.6	+08
108	3.6	−02	244	2.7	+16	454	8.4	+19	621	7.3	+20
112	7.5	+11	246	10.4	+14	455	3.0	+08	625	9.2	+09
118	7.9	+13	254	5.5	+04	458	4.1	−02	630	8.7	+09
124	5.6	+09	257	8.1	+06	463	5.2	+03	632	8.9	+13
130	9.0	+16	270	8.8	+19	472	10.3	+14	643	10.1	+19
132	7.9	+13	272	8.8	00	473	7.8	+15	644	7.5	+12
133	10.5	+19	280	7.8	+03	477	9.3	+04	654	8.1	+06
134	7.8	+11	290	8.5	+09	486	9.0	+15	655	8.8	+36
135	2.9	00	295	8.6	+07	489	2.7	00	656	8.5	+30
139	9.0	−06	300	3.6	+03	496	6.2	+02	658	9.8	+33
140	7.9	00	304	10.7	+14	497	9.6	+18	659	6.1	+07
143	7.5	+14	307	8.4	+17	500	5.3	−02	665	6.8	+11
146	8.9	+10	308	5.5	−06	508	4.5	+10	669	8.3	−01
147	9.4	+07	313	7.3	+14	509	5.7	+12	680	9.3	+16
149	9.6	+04	314	8.8	00	511	1.1	+05	689	4.4	+06
151	7.5	+08	323	11.1	+17	513	10.0	+21	691	6.3	+20
152	8.1	+07	328	3.9	+05	516	6.4	+12	692	3.8	+09

Table VIII (cont.)

No.	$m-M_0$	E	No.	$m-M_0$	E	No.	$m-M_0$	E	No.	$m-M_0$	E
693	3.9	−06	812	7.7	+18	909	8.5	+18	1032	5.2	−18
697	10.6	+16	815	6.9	+26	918	6.2	+22	1035	9.0	+15
702	10.3	+20	819	6.0	+08	919	4.3	+07	1036	8.0	+21
703	7.3	+24	820	8.6	+21	920	6.0	+13	1038	7.7	+04
708	8.4	+05	821	2.2	+05	921	6.1	+19	1040	6.1	−02
709	11.2	+06	825	8.3	+25	928	8.6	+29	1041	5.2	+09
712	8.8	−08	827	9.1	+18	929	7.1	+09	1042	5.8	+14
717	3.9	+07	828	5.0	−01	930	3.4	+03	1044	8.9	+14
720	10.1	+27	830	4.6	+33	932	6.0	+06	1045	5.5	−03
724	6.0	+09	832	5.7	+16	938	7.0	+14	1049	10.1	00
731	8.2	−01	834	5.7	+14	939	9.5	+15	1051	9.8	+02
733	8.1	+24	836	5.7	+12	940	9.9	+15	1053	8.4	+16
739	4.8	+06	837	10.1	+13	942	8.2	−04	1063	3.6	+06
748	9.4	+09	838	4.6	+24	943	11.0	−01	1068	9.8	+17
754	5.7	+05	839	2.0	+19	947	5.8	+05	1070	9.2	+02
755	5.5	−01	841	4.6	+08	949	6.2	+07	1076	8.1	−15
756	8.6	+09	843	9.4	+11	950	5.7	+13	1077	7.0	+13
766	9.6	+46	844	6.6	00	952	3.8	+07	1080	7.1	−02
770	9.2	+35	845	7.4	+17	953	5.7	−08	1093	8.6	+08
771	6.2	−02	846	4.0	+14	955	2.9	+09	1094	4.0	+10
772	7.2	+14	847	3.1	+17	959	3.9	+04	1106	6.4	+19
773	7.5	+10	850	7.8	+12	961	8.3	+18	1109	5.9	+08
774	4.9	−01	851	9.1	−05	963	7.8	+10	1110	7.9	00
776	5.8	+17	853	5.7	−03	964	9.8	+07	1114	6.4	+01
778	7.9	+33	856	7.9	+35	965	8.8	+12	1116	8.1	+19
781	9.6	+15	857	4.7	+06	966	8.9	+12	1120	6.0	+03
782	5.3	+05	863	10.5	+29	970	6.8	+22	1124	8.3	+18
784	9.6	+28	866	7.5	+30	983	5.8	+13	1128	9.5	+06
785	10.6	+22	867	2.8	+14	984	6.1	+14	1131	5.6	+07
786	8.3	+28	868	6.3	+08	990	5.8	−04	1133	5.1	+05
788	6.1	−10	869	8.3	+17	992	5.9	+05	1135	5.6	+11
789	4.2	+23	870	1.8	+14	993	9.5	+22	1137	7.5	+18
792	4.4	−13	874	9.4	+19	994	5.6	+11	1139	8.1	+07
794	7.6	−09	879	5.8	+12	1002	5.7	+05	1140	9.1	+01
797	8.4	+43	880	9.2	+15	1005	5.4	+14	1141	4.9	+24
801	2.6	+15	882	8.1	+11	1006	7.9	+20	1143	5.1	−05
802	5.4	+07	887	2.6	+14	1010	5.5	+02	1144	8.6	+24
804	5.0	+01	891	9.0	+28	1013	6.4	+14	1152	5.7	+12
807	7.7	+24	893	7.7	+21	1020	5.1	+05	1153	8.1	+19
811	7.7	+04	904	7.9	+26	1023	6.1	−04			

100 parsecs, and that the excess values are not changed from $m-M_0=5$ to 7. Accordingly we only have "clear space" between the dark nebula, which is the nearest one (hereafter referred to as DC1), and the next nebula, called DC2. DC2 must be situated near $m-M_0=7$, as the interval 7–8 gives a value indicating that the absorption caused by DC2 is fully effective. Using the preliminary value of $A/E=10$ we thus find that the second dark nebula is situated at a distance of approx. 160–180 parsecs.

At greater distance we reach "clear space" again, but later it will be shown that at a distance of about 600 parsecs we have a third dark nebula, DC3.

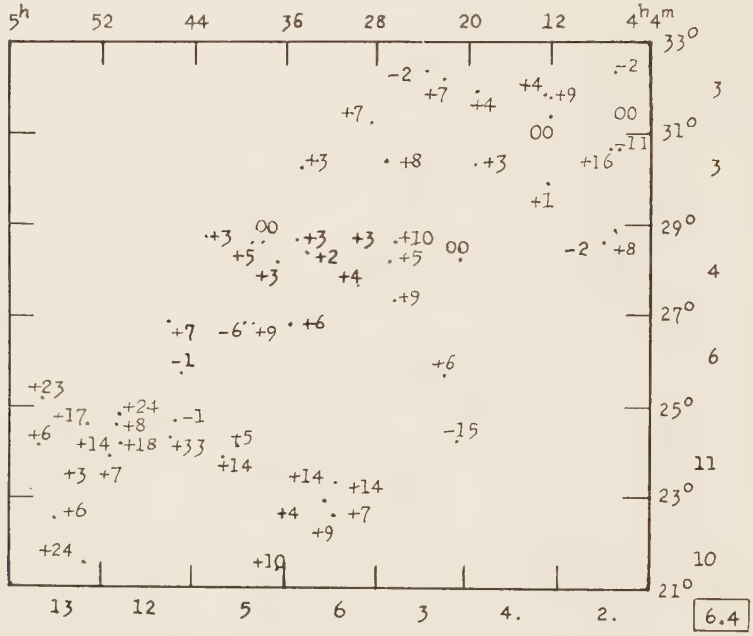

Fig. 8. The distribution of colour excesses; $m - M_0 \leq 5$.

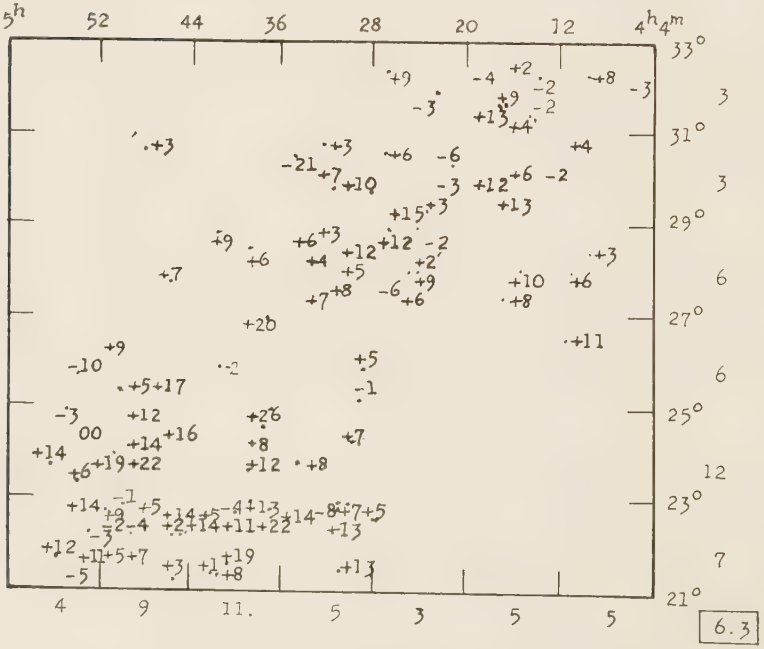

Fig. 9. The distribution of colour excesses; $5 < m - M_0 \leq 7$.

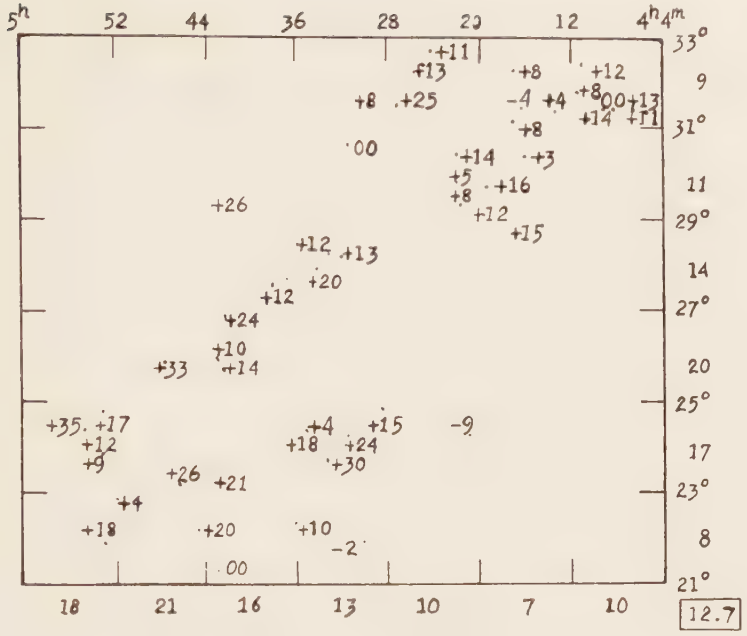

Fig. 10. The distribution of colour excesses: $7 < m - M_0 \leq 8$.

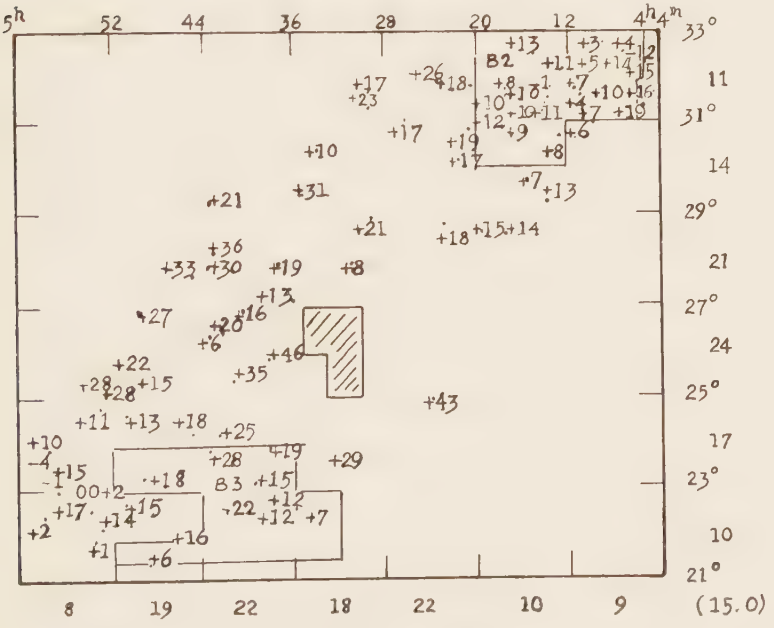

Fig. 11. The distribution of colour excesses if only A0σ and A0μ stars are used; $m - M_0 > 8$.

Chapter VII

A detailed discussion of some interesting regions

1. The dark nebula DC1

Even though the preceding colour-excess maps clearly show the distribution of obscuring material, there are nevertheless some interesting facts which must be treated in greater detail. Therefore a few Wolf diagrams (from a total number of more than 400) of special interest will be given, since they, in addition, give rise to some conclusions regarding the stellar distribution in Auriga and Taurus. By means of the "standardized Wolf-diagrams" (see MALMQUIST [12]) it is also possible to show that the dark clouds must be treated as screens, and therefore some of these diagrams will be given as well.

The method used in calibrating the value of $A/E = k$, will at the same time be apparent.

We will now treat the first dark nebula, DC1, except the darkest region, which will be investigated later. It is obvious that only stars of low luminosity can be used. In the following table the distribution of A5, F0, F2, F5, F8, G0, and dG5 stars is given. The region used is stated beneath the table. The total area is 40.0 square degrees. As has been mentioned already the preliminary analysis showed that Seeliger's law was valid within the investigated region. It was, moreover, possible to determine the Wolf curves when the absorption was taken into account; that is, the Wolf diagrams of an imaginary area, completely free from obscuration, were constructed. In a few instances it was, however, very difficult to decide if the

Table IX

m	A5, F0				F2, F5				F8, G0				dG5			
	Taurus		Auriga		Taurus		Auriga		Taurus		Auriga		Taurus		Auriga	
	$A(m)$	$N(m)$	$A(m)$	$N(m)$	$A(m)$	$N(m)$	$A(m)$	$N(m)$	$A(m)$	$N(m)$	$A(m)$	$N(m)$	$A(m)$	$N(m)$	$A(m)$	(Nm)
−6.5					1	1					2	2				
7.0					0	1			1	1	0	2				
7.5					0	1			1	2	1	3	1	1		
8.0	1	1	3	3	1	2			2	4	1	4	1	2		
8.5	0	1	1	4	0	2	4	4	1	5	5	9	0	2	1	1
9.0	3	4	5	9	0	2	3	7	2	7	12	21	3	5	1	2
9.5	2	6	7	16	4	6	10	22	1	8	17	38	2	7	3	5
10.0	3	9	13	29	10	36	16	38	29	17	24	62	6	13	11	16
10.5	7	16	22	51	4	10	23	61	10	27	44	106	1	14	8	24
11.0	9	25			11	21			13	40			5	19		
11.5	9	34			19	40			14	54			7	26		
12.0	15	49			33	73			30	84			—	—		

32°: 4^h6–26^m, 31: 8–28, 30: 12–32, 29: 12–32, 28: 20–38, 27: 30–42, 26: 39–43, 23: 32–56, 22: 32–44, 21: 32–52 – 30′.

Taurus: 40.0 sq. deg. Auriga 49.6 sq. deg.

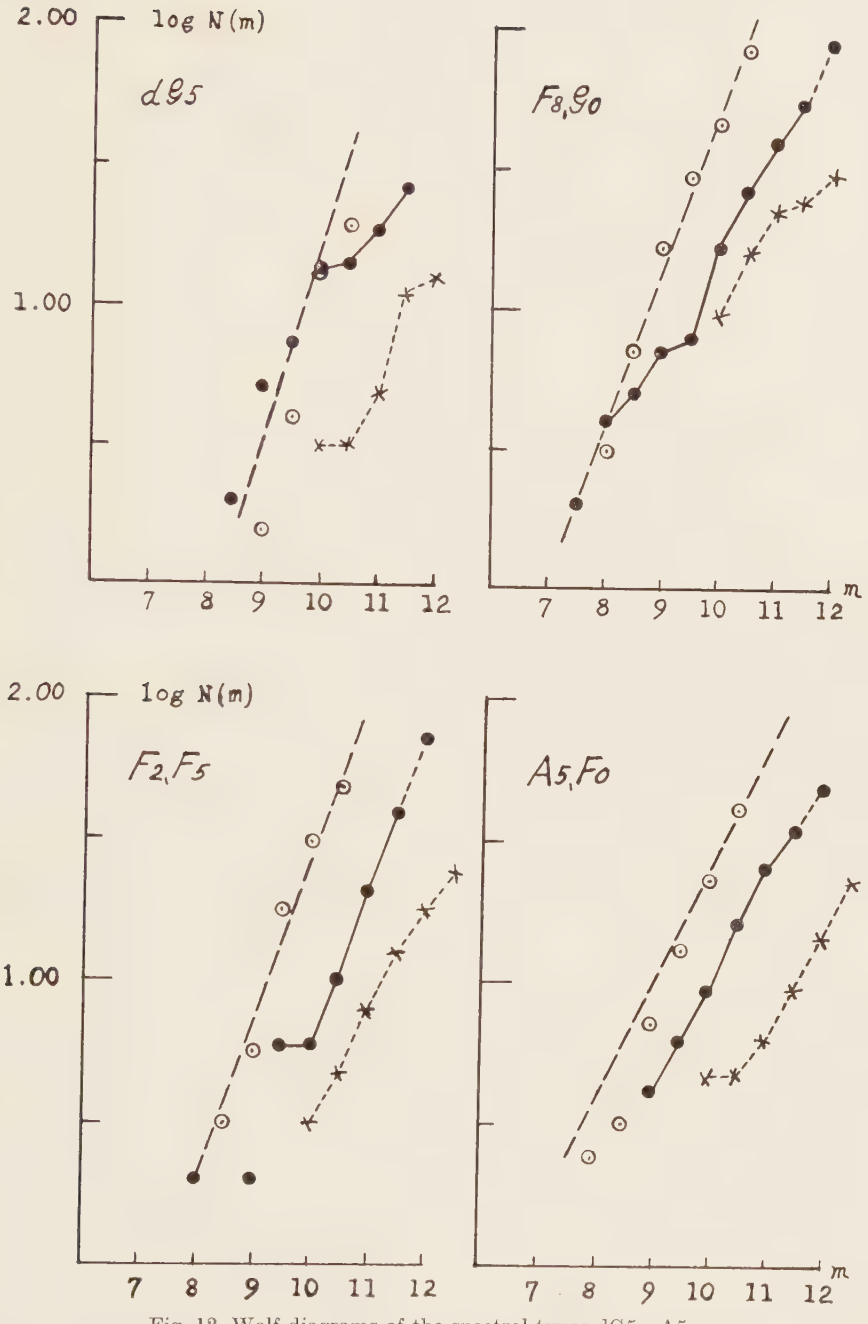

Fig. 12. Wolf diagrams of the spectral types dG5 – A5.

– – – the curve of the supposed bright region, B′.
⊙ ⊙ ⊙ ⊙ ⊙ ⊙ ⊙ ⊙ ⊙ the curve of the Auriga stars.
● ● ● ● ● ● ● ● ● the curve of the Taurus stars. Region A1.
× × × × × × × × × the curve of the Taurus stars. Region D2.

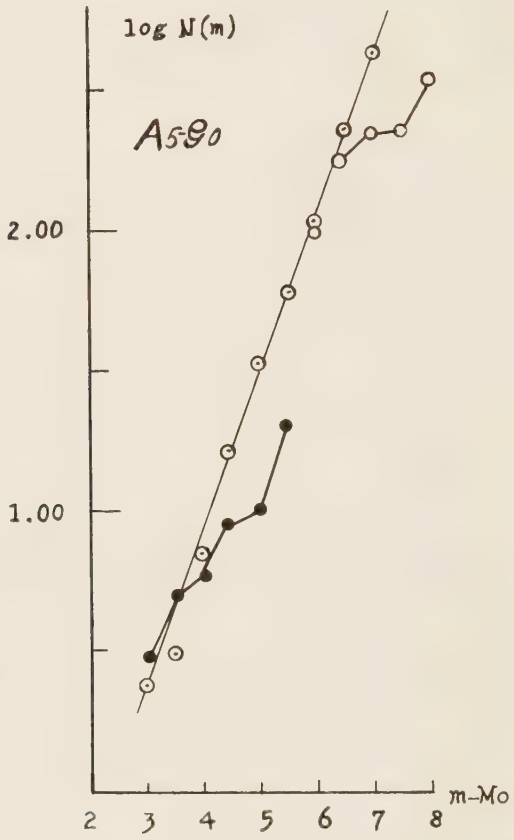

Fig. 13. The standardized Wolf diagram from the bright region B1. The same notations as before have been used. The curve of the bright region B1 is denoted by ○.

irregularities found in the log $N(m)$-curves were real or merely caused by accidental variations, and therefore a more direct comparison with an actually existing bright area was highly desirable. Fortunately there is such an area not far away. In Auriga SCHALÉN [18, 19] has determined the distribution of stars of different spectral classes in the Uppsala system and therefore a comparison with the bright areas N + B found there must be of great interest, especially as the classification is based directly on visual classification on the spectral plates; this means a possibility of testing the existence of possible differences between the original Uppsala system and the present one. It is true that the areas are not situated on exactly the same galactic latitude; but a division of the Auriga material according to different galactic latitudes shows that only in the case of Bτ, Bτ −, A0σ +, and A0σ stars a correction must be applied. In the actual case, the B-stars are not used; as for the A0σ + and A0σ stars a glance at Table 24 on p. 73 in [18] shows that the area density in B is twice as large as the area density in N. Hence it is easy to reduce the distribution of all σ-

Table X

Sp.U. / m	A2, 3	A5, F0	F2, F5	F8, G0	dG5	g-stars
	$N(m)$	$N(m)$	$N(m)$	$N(m)$	$N(m)$	$N(m)$
−10	3	0	2	4	0	0
10.5	3	0	2	5	0	2
11	3	1	2	7	1	4
11.5	5	1	3	9	1	5
12	7	2	6	9	1	6

23°: 4^h44–52^m, 22: 44–52.
Area: 2.0 sq. deg.

stars to region N. No other correction has been applied because of the uncertainty of such corrections.

From the diagrams it is immediately found that the Wolf curves of the supposed bright region and of the region B + N in Auriga are almost identical. Only in the case of A5, F0-stars does there seem to be a slight difference. Thus it seems as if the "bright region curves" used were rather well founded. Nevertheless it must still be desirable to prove that a really bright region, situated *within* the actual region, will show the presumed distribution.

As already mentioned, there exists only very small areas not covered by DC1. The largest one is situated within the area with the limits 4^h44^m–52^m and 22°–23°. Table X gives the distribution of the stars of different spectral types within this small region of only 2 square degrees. It is, of course, impossible to compare the spectral types individually and therefore we apply the method of the standardized Wolf diagram. Figure 13 shows the result. It is quite evident, that the curves corresponding to the log $N(m)$ curve of a bright region must be regarded as well-determined. At the same time we have the possibility of determining the distances at which DC1 and DC2 are situated. From the figure we get $m - M_0 \sim 4.0$ and 6.5, respectively, which indicates the distances 65 parsecs and 200 parsecs, respectively.

2. The dark nebulae DC2 and DC3

It is a well-known fact, that when dark clouds are to be investigated it is necessary to select very carefully areas of different obscuration. On the other hand, a division into quite homogeneous regions, if at all possible in the actual case, will give rise to serious problems caused by the smallness of the star numbers from a statistical point of view. In such a case the best method must, of course, consist in reducing the original apparent magnitudes for the absorption caused by, *e.g.* DC1 when DC2 is to be investigated, and so on. If *perfect* colour excesses of all stars could be obtained the problem might be rather simple, but in the actual case, however, we cannot use individual excesses, because of the great dispersion s_i within most spectral classes. Therefore only mean values give comparably reliable information about the distribution of dark material. It may be mentioned that in most cases the excesses alone are not sufficient; an inspection of the apparent distribution of the stars must also be utilized. An example may illustrate the method which has been used. In the same time some information about the dark cloud DC3 is given.

Table XI

Sp.U. / m	A0σ+				A0σ				A0μ				A2, 3				g-stars			
	B2		B3		B2		B3		B2		B3		B2		B3		B2		B3	
	$A(m)$	$N(m)$	$A(m)$	$N(m)$	$A(m)$	$N(m)$	$A(m)$	$N(m)$	$A(m)$	$N(m)$	$A(m)$	$N(m)$	$A(m)$	$N(m)$	$A(m)$	$N(m)$	$A(m)$	$N(m)$	$A(m)$	$N(m)$
−7.0											1	1								
7.5											1	2							1	1
8.0			1	1	1	1					0	2	1	1	1	1	1	1	0	1
8.5			1	2	0	1					0	2	0	1	1	2	1	2	1	2
9.0			0	2	2	3	1	1			0	2	1	2	0	2	1	3	0	2
9.5			0	2	1	4	0	1	2	2	0	2	2	4	0	2	2	5	2	4
10.0			0	2	3	7	3	4	2	4	1	3	2	6	1	3	5	10	1	5
10.5			0	2	0	7	0	4	2	6	2	5	2	8	2	5	3	13	4	9
11.0	1	1	0	2	1	8	0	4	6	12	2	7	8	16	0	5	5	18	4	13
11.5	0	1	0	2	2	10	1	5	0	12	2	9	6	22	3	8	9	27	6	19
12.0	0	1	0	2	3	13	1	6	3	15	1	10	6	28	6	14	3	30	5	24

B2: 32°: 4^h5–20^m, 31: 6–20, 30: 12–20. B3: 23: 36–52, 22: 32–44, 21: 32–52>30.
B2: 9.3 sq. deg. B3: 9.5 sq. deg.

In the following Table XI the distribution of A0σ+, A0σ, A0μ, A2,3, and g-stars is given. The regions used are stated beneath the table. The areas are: B2: 9.3 square degrees; B3: 9.5 square degrees.

This table will immediately show that $N(m)$ for region B3 lies about 0.5 magn. behind $N(m)$ for region B2. Thus for the $N(m)$-numbers of g-stars, for instance, we have from magn. 9.0 (B2) and 9.5 (B3) respectively the pairs of numbers: 3,4; 5,5; 10,9; 13,13; 18,19; 27,24. The maps of excesses also reveal a difference of about 0.5 magn. between B2 and B3. Therefore the original apparent magnitudes in the region B3 are diminished by 0.5 magn. The following values appear:

Table XII

Sp.U. / m	A0σ, σ+		A0μ		A2, 3		g-stars	
	Taurus	Auriga	Taurus	Auriga	Taurus	Auriga	Taurus	Auriga
7.5	1	8		6	1	2	1	4
8.0	3	15		9	3	2	3	10
8.5	4	20		12	3	7	4	18
9.0	6	38		28	4	12	7	35
9.5	10	71	3	40	7	25	10	58
10.0	13	108	7	77	11	48	19	94
10.5	13	156	11	140	13	91	26	157
11.0	15		19		24		37	
11.5	19		20		36		51	

Taurus: 18.8 sq. deg. Auriga 49.6 sq. deg.

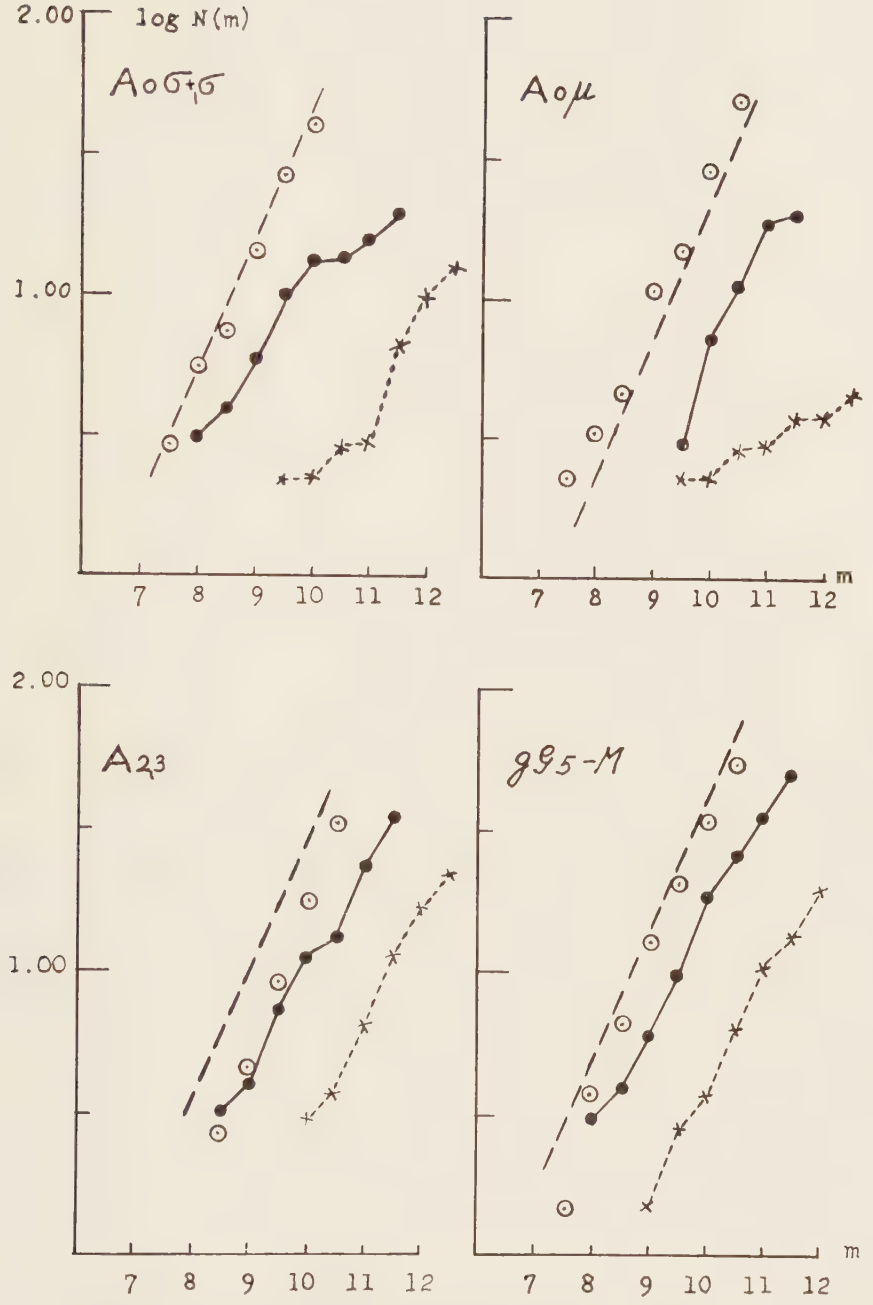

Fig. 14. Wolf diagrams of the spectral types A0σ + − A3, and gG5–M-stars. The same notations as before have been used.

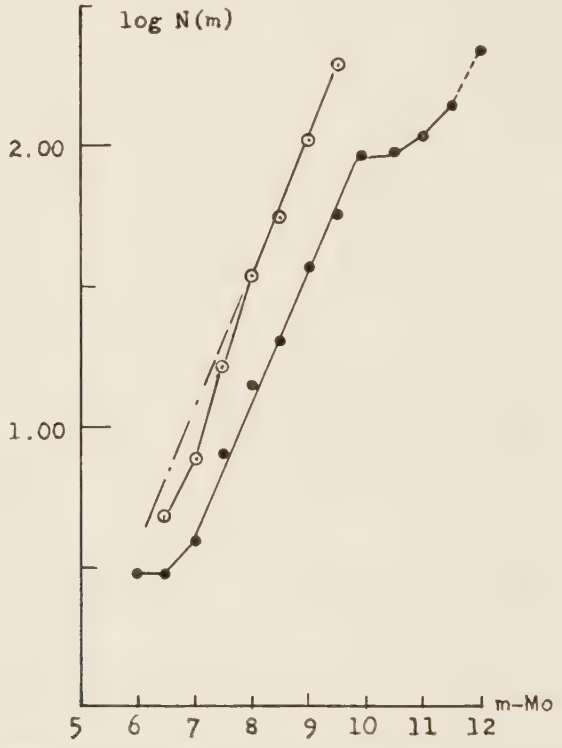

Fig. 15. The standardized Wolf diagram from the bright regions B2 and B3. A0σ + − A_3-stars are used.

We find from the diagrams, once more, that the Wolf curves of the supposed bright region and of the region B + N in Auriga are almost identical. Only in the case of A2,3-stars there is a pronounced difference, most probably caused by a slight deviation in the classifying of A0μ and A2,3 stars in Auriga and in Taurus.

To give a clear picture of how the two dark clouds DC2 and DC3 affect the log $N(m)$-curves it may be suitable to use the standardized Wolf diagram once more. It is a well-known fact that by using such a diagram we can combine the data for different spectral types, thus diminishing the accidental errors but still preserving the real peculiarities. A condition which must be fulfilled is, of course, that the absolute magnitudes of the different spectral types be known with reasonable accuracy. Figure 15, above, illustrates the result. It will immediately appear that the position of DC3 can be determined once more. One obtains a value somewhat less than 200 parsecs. The distance of the dark cloud DC3 is also easily found; the distance modulus beeing $m - M_0 \sim 9$, or the distance is about 650 parsecs. If the apparent absorption curve is constructed, one more screen at about $m - M_0 = 7.5$ is vaguely indicated. Using an A2,3-distribution according to the line B' in Fig. 14, this indication will disappear, however. The two $N(m)$-curves are then exactly parallel. The diagram also shows that the dark material is really concentrated into screens between which there is no perceptible absorption; this conclusion could also be arrived at from the maps of the distribution of excesses.

3. The darkest regions centered at $\alpha = 4^h32^m$; $\delta = 26^\circ$

If the darkest regions are investigated by the use of the present material one finds that the low limiting magnitude does not admit of any reliable conclusions. On the other hand, the Wolf diagrams do not exclude the previously found distances of the clouds DC1 and DC2. The following table contains the distribution of the different spectral types in the usual manner. The area used is 25.0 square degrees; a practically opaque region near the centre has been excluded. The Wolf diagrams are found in Figs. 12 and 14.

Table XIII

Sp.U. / m	A0σ+, σ		A0μ		A2, 3		A5, F0		F2, F5		F8, G0		dG5		g-stars	
	$A(m)$	$N(m)$	$A(m)$	$N(m)$	$A(m)$	$N(m)$	$A(m)$	$N(m)$	$A(m)$	$N(m)$	$A(m)$	$N(m)$	$A(m)$	$N(m)$	$A(m)$	$N(m)$
−9.0	2	2	0	0	1	1	3	3	1	1	2	2	1	1	2	2
9.5	1	3	3	3	0	1	0	3	1	2	3	5	0	1	2	4
10.0	0	3	0	3	3	4	0	3	0	2	1	6	1	2	2	6
10.5	1	4	1	4	2	6	0	3	1	3	4	10	0	2	3	9
11.0	0	4	0	4	3	9	1	4	2	5	4	14	1	3	5	14
11.5	5	9	1	5	7	16	2	6	3	8	2	16	4	7	4	18
12.0	4	13	0	5	7	23	3	9	3	11	3	19	1	8	9	27
12.5	4	17	1	6	7	30	5	14	4	15						

D2: 29°: 4^h5–$19^m < 30'$, 25–40, 28: 5–16, 27: 10–20, 26–30, 26: 18–39, 25: 30–50, 24: 22–44.
Area: 25.0 sq. deg.

The diagram of the dG5-stars indicates absorbing material at a distance still smaller than 65 parsecs: a value of 30–40 parsecs is vaguely indicated, but the star-number is of course too small to provide any reliable data. If we combine that result with Fig. 11, it seems possible, however, to draw some conclusions also about the distribution of dark material within the darkest regions. If DC1 includes dark material within the distances 0–65 parsecs we find from Fig. 11 that the absorption in the central parts must begin at distances ~ 0. In the darkest region we have no single colour excess available, but round that region a few excess values are to be found: +46, +43, +35, and +29; a fact which seems to indicate a total absorption within the central region of more than 4 magnitudes.

4. A comparison with the results found by McCuskey

At last, the results now found may be compared with the earlier investigation performed by McCuskey. We find that McCuskey's nebula was situated at a distance of 113 ± 39 parsecs. If the method used by McCuskey is taken into account, we find that the two nebulae DC1 and DC2 are both situated near the limits of the mean error interval, 74 and 152 parsecs; this means that McCuskey has treated the two nebulae as a single one.

If Table 1 on p. 471 in [16] is investigated, we find that the star-numbers in the case of B8–A0 stars also indicate the situation of the dark nebula DC3. The colour excesses from region I in Fig. 3 indicate the nebula DC3 too, but, as already men-

tioned, the investigated areas must be divided into homogeneous regions if any definite conclusions are to be found from the distribution of the colour excesses.

From Fig. 3 we may arrive at some conclusions about the darkest region within DC1. From the Wolf diagram of McCUSKEY's region F we find a total absorption of about 5 magnitudes. Further we see that the general star counts have only reached the clear space region between DC1 and DC2. We cannot expect that the space behind the third nebula has been reached before the star counts are extended to magnitude 20–21.

CHAPTER VIII

The relation between absolute and selective absorption

The relation between absolute and selective absorption in the case of the special spectral colour used by the present author has been investigated before at this Observatory, *e.g.* by WERNBERG [27]. He concluded that the selective absorption was 10–11 per cent of the total absorption. The material on which the investigation was based consisted of determinations of mutually connected values of $\bar{A}$ and $\bar{E}$ (hereafter denoted by $(\bar{A}, \bar{E})$) in Auriga, Cygnus (determinations performed by SCHALÉN) and Cepheus (SCHALÉN and WERNBERG). The very interesting result is graphically illustrated on p. 105, Fig. 46 in [27]. WERNBERG finds from this figure that the dark clouds in Auriga, Cepheus and Cygnus all lead to the same ratio between the two kinds of absorption. It must therefore, of course, be of interest to compare the present values in Taurus with those found earlier, and thus all available points have been plotted in the following Figure 16.

A few words may be said about the Taurus determinations. The points corresponding to values larger than (1.00, 0.10) are somewhat uncertain because of the fact that it has not been possible to use only those areas in which the absorption is almost homogeneous. Corrections have been added in order to eliminate the systematic errors which thus arise. It is easy to show that the $\bar{E}$-values found from an area with unregular obscuration must always be too small, compared with the $\bar{A}$-value obtained from the log $N(m)$-curves; this means that a positive correction must be added to the $\bar{E}$-values originally obtained. As an example, let us consider three equal areas within which the absorption is constantly 0.5, 1.0, and 1.5 magnitudes; if these areas are treated together and if the β-value is 0.5 we shall find that a correction of 10 per cent is necessary. Fortunately we can estimate the variation in obscuration by means of the individual colour excesses, but nevertheless small errors may occur at the points mentioned above. I suppose, however, that these errors are only of accidential character.

As seen from the figure the Taurus values are scattered around the straight line — — — drawn through the origin. The points based on earlier determinations seem to follow the same line, at least approximately. It must be pointed out, however, that there is no reason at all to presuppose that the straight line (if the relation is really a straight line at all) must pass through the origin; therefore I have applied the method of least squares in order to obtain the most probable value of the coeff. k in $A = k \cdot E$. If the method is applied for the earlier determinations we get:

$$k = 7.8 \pm 0.8 \text{ and } A_0 = 0.21 \pm 0.10$$

The Taurus values: $k = 8.6 \pm 0.7$ and $A_0 = 0.09 \pm 0.05$

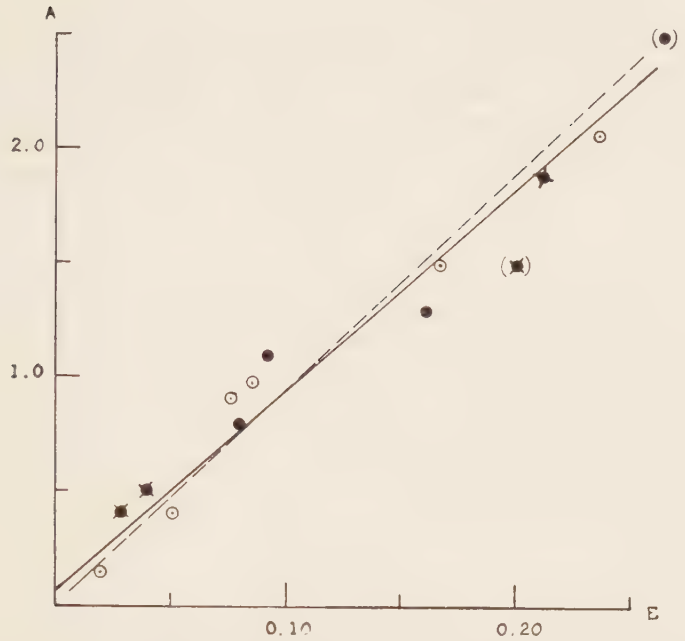

Fig. 16. The relation between selective and total absorption. Determinations performed by ■ SCHALÉN, ● WERNBERG and ○ ADOLFSSON.

In both cases we thus obtain a positive value of the ordinate at the origin. There are of course many things which may cause such an effect; among them the influence of a neutral absorption or somewhat too high normal colours may be mentioned.

We conclude from the preceding discussion that it seems as if the relation $A = k \cdot E$ in the Taurus region here investigated may be considered as a good first approximation, at least. The most probable value is 8.6. (This value corresponds to 3.9–4.0 in the international colour system.)

Summary

A region in Taurus, situated between 4^h–5^h in R.A. and between 21°–33° in decl. ($-10° - -15°$ in galactic latitude) has been investigated by means of spectra, magnitudes, and colours. The existence of normal colours has been confirmed, and normal spectral colours have been determined. It has been shown that at least three different dark clouds (screens) separated by regions of clear space are situated in the direction of space investigated. The first dark nebula, DC1, is situated at a distance of 30–70 parsecs (and perhaps still nearer at the darkest areas) and covers almost the whole area. There are only small spots with no absorption, the largest at 4^h44^m-52^m and 22°–23°; the obscuration is about 0.5 magnitudes at the edges and increases towards the centre (at about $\alpha = 4^h30^m$, $\delta = 26°$) where a value of at least 4 magn. is reached. The next nebula, DC2, is situated at about 175 parsecs

and has an average absorption of about 1 magn. The third dark nebula is situated at about 600 parsecs and absorbs, most probably, about 1.5 magn.

A determination of the relation between absolute and selective absorption shows as a result that the selective absorption is 11–12 per cent of the total absorption.

Comparisons with the Auriga region indicate that the distribution of stars in Taurus and Auriga is identical.

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